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Green Cities and Health: a question of scale?

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Green cities and health: a question of scale?

WHAT IS ALREADY KNOWN?
Access to natural settings, such as urban green space, has been associated with better health in many studies. However, no studies have tested this association at the scale of entire cities.

WHAT THIS STUDY ADDS?
This study is the first to investigate whether greener cities are healthier cities, at the scale of entire cities.

Unexpectedly, we found little association between green space and health among American cities, which may reflect the fact that, in the USA, greener cities are more sprawling cities. The negative effects of sprawl may eclipse any positive effects of green space.

If we green our cities without attention to the form the green spaces take, and the implications of green space provisions for other societal functions, such as transportation, there may be no benefit to population health.

ABSTRACT

Background
Cities are expanding and accommodating an increasing proportion of the world's population. It is important to identify features of urban form that promote the health of city dwellers. Access to green space has been associated with health benefits at both individual and neighbourhood level. We investigated whether a relationship between green space coverage and selected mortality rates exists at the city level in the USA.

Methods
An ecological cross-sectional study. A detailed land use dataset was used to quantify green space for the largest US cities (n = 49, combined population 43 million). Linear regression models were used to examine the association between city-level 'greenness' and city-level standardised rates of mortality from heart disease, diabetes, lung cancer, motor vehicle fatalities, and all causes, after adjustment for confounders.

Results
There was no association between greenness and mortality from heart disease, diabetes, lung cancer, or automobile accidents. Mortality from all causes was significantly higher in greener cities.

Conclusion
While considerable evidence suggests that access to green space yields health benefits, we found no such evidence at the scale of the American city. In the USA, greener cities tend also to be more sprawling, and have higher levels of car dependency. Any benefits that the green space might offer seem easily eclipsed by these other conditions and the lifestyles that accompany them. The result merits further investigation as it has important implications for how we increase green space access in our cities.

Keywords: green space, urban health, USA, environmental epidemiology, GIS

INTRODUCTION

Urban areas account for slightly over half the world's population, and are expected to absorb substantial population growth over the next four decades.[1] Urbanisation poses a substantial public health challenge,[2] hence urban design that promotes health is a priority. There is mounting evidence that open, vegetated environments, or green spaces, have benefits for the health of urban residents.[3-8] Possible causal mechanisms include the psychologically and physiologically restorative effects of contact with nature,[9, 10] the facilitation of social contacts,[11] opportunities for physical activity,[12, 13] and the removal of air pollution from the atmosphere.[14] These mechanisms may be mutually reinforcing; experiments indicate that physical activity yields more complete restoration when performed in green areas than when performed in constructed urban spaces.[9, 10] Literature examining relationships between green space and health is emerging from around the world, although studies from northern Europe currently dominate numerically. This study focused on the USA, where research in this field has been generally local in scale, considered specific population subgroups, and measured intermediate behavioural or physiological outcomes rather than forms of morbidity or mortality.[9, 15-18]

Most studies examining relationships between green space and health have examined individual or neighbourhood-level health benefits. Many also utilise the availability of green space within and/or around the neighbourhood of residence to measure exposure to green space, while acknowledging that exposure may also occur outside these zones. Greener neighbourhoods are, all else being equal, healthier neighbourhoods.[4, 5, 7] However, the hypothesis that greener *cities* are healthier cities has not been tested. Cities are appropriate units of analysis because they represent discrete entities; they are social and physical ecosystems in which exposure to green spaces may be comparatively limited, but particularly valuable. Importantly, cities are also often planning units, and hence targets for the application of knowledge about nature and health.[19] Cities also have many other built and physical environmental features which might hold influence over population health. In this study therefore, we investigated the relationship between green space and mortality, with individual American cities the units of analysis.

Our research question was "is there an independent association between the green space coverage of cities in the USA and their all cause and cause specific mortality rates?"

METHODS

Geographical unit of analysis

Our intention was to include the largest cities in the contiguous US (n = 53, totalling 16% of US population) in the study. We needed data for each 'city' describing green space coverage, all-cause and cause specific mortality rates, and potential confounders. These data stemmed from different sources and thus it was essential to make the geographical definition of each city boundary as consistent as possible to ensure that we were measuring exposure, outcome and confounders for the same population. The prime definition of each city was its US Census ‘Incorporated City’ boundary. However, four cities (Atlanta, GA; Fresno, CA; San Diego, CA; and Sacramento, CA) were excluded because the mortality rates available to us also covered a sizeable population outside the Incorporated City boundary.[20] The 49 remaining cities had an average size of 416 km^2, a total population of 43 million, and an average population of 0.9 million. Geographical and sociodemographic characteristics for each city are provided in Table 1.

Table 1. Characteristics of each city in the study, ranked in decreasing order of green space coverage.

City	Population (2000)‡	Area (km^2)†	Median household income ($, 1999)‡	Non-Hispanic white population (%, 2000)‡	Green space coverage (% by area) (+ 95% confidence interval)†
Nashville-Davidson,TN	569,891	657	39,232	65.1	68.7 (66.1 to 71.3)
Colorado Springs, CO	360,890	516	45,081	75.3	68.6 (66.5 to 70.7)
Charlotte, NC	540,828	585	46,975	55.1	68.0 (65.7 to 70.4)
Virginia Beach,VA	425,257	400	48,705	69.5	66.5 (64.2 to 68.7)
Jacksonville, FL	735,617	830	40,316	62.2	65.9 (63.2 to 68.5)
Austin, TX	656,562	479	42,689	52.9	65.5 (63.8 to 67.3)
Albuquerque, NM	448,607	466	38,272	49.9	65.2 (63.1 to 67.3)
Wichita, KS	344,284	452	39,939	71.7	62.3 (60.0 to 64.6)
Fort Worth, TX	534,694	553	37,074	45.8	61.3 (59.5 to 63.2)
Tucson, AZ	486,699	349	30,981	54.2	61.2 (59.6 to 62.8)
San Antonio, TX	1,144,646	838	36,214	31.8	60.9 (59.4 to 62.5)
Memphis,TN	650,100	587	32,285	33.3	60.6 (58.8 to 62.5)
Indianapolis, IN	791,926	865	40,051	67.7	60.4 (58.7 to 62.1)
Arlington, TX	332,969	248	47,622	59.6	59.0 (56.7 to 61.3)
Dallas, TX	1,188,580	754	37,628	34.6	57.3 (55.6 to 59.0)
Tulsa, OK	393,049	343	35,316	67.1	57.2 (55.1 to 59.4)
Cincinnati, OH	331,285	206	29,493	52.5	57.2 (54.0 to 60.5)
Kansas City, MO	441,545	461	37,198	57.6	56.9 (54.2 to 59.6)
Mesa, AZ	396,375	241	42,817	73.2	56.2 (53.4 to 58.9)
El Paso, TX	563,662	386	32,124	18.3	56.0 (53.0 to 59.0)
Omaha, NE	390,007	298	40,006	75.4	55.1 (53.1 to 57.1)
Phoenix, AZ	1,321,045	779	41,207	55.8	53.3 (51.8 to 54.7)
Louisville/Jefferson Co., KY	693,604	160	39,457	76.5	53.1 (49.6 to 56.7)
Denver, CO	554,636	255	39,500	51.9	52.6 (50.7 to 54.4)
Columbus, OH	711,470	502	37,897	66.9	52.5 (50.7 to 54.3)
Oklahoma City, OK	506,132	527	34,947	64.7	52.3 (50.4 to 54.3)
Pittsburgh, PA	334,563	143	28,588	66.9	47.5 (45.1 to 50.0)
Washington, DC	572,059	159	40,127	27.8	47.3 (44.8 to 49.8)
Cleveland, OH	478,403	201	25,928	38.8	45.7 (44.3 to 47.1)
Houston, TX	1,953,631	1316	36,616	30.8	45.5 (44.1 to 46.8)
Portland, OR	529,121	404	40,146	75.5	44.5 (42.3 to 46.7)
Milwaukee, WI	596,974	249	32,216	45.4	43.4 (41.9 to 44.9)
San Jose, CA	894,943	329	70,243	36.0	43.3 (41.8 to 44.9)
Baltimore, MD	651,154	210	30,078	31.0	43.3 (40.2 to 46.3)
St. Louis, MO	348,189	160	27,156	42.9	42.8 (41.3 to 44.3)

Miami, FL	362,470	93	23,483	11.8	42.0 (39.5 to 44.5)
New Orleans, LA	484,674	184	27,133	26.6	41.8 (40.0 to 43.5)
Minneapolis, MN	382,618	148	37,974	62.5	41.5 (39.3 to 43.7)
Las Vegas, NV	478,434	214	44,069	58.0	40.4 (38.5 to 42.3)
Los Angeles, CA	3,694,820	1134	36,687	29.7	39.5 (38.3 to 40.6)
Philadelphia, PA	1,517,550	351	30,746	42.5	38.0 (36.0 to 40.1)
Seattle, WA	563,374	218	45,736	67.9	36.9 (34.5 to 39.2)
Oakland, CA	399,484	144	40,055	23.5	36.2 (32.5 to 39.9)
Detroit, MI	951,270	370	29,526	10.5	35.2 (34.2 to 36.2)
Chicago, IL	2,896,016	591	38,625	31.3	30.6 (29.9 to 31.3)
Boston, MA	589,141	125	39,629	49.5	29.8 (27.5 to 32.1)
Long Beach, CA	461,522	137	37,270	33.1	29.1 (27.1 to 31.0)
San Francisco, CA	776,733	125	55,221	43.6	25.8 (23.9 to 27.7)
New York, NY	8,008,278	629	38,293	35.0	19.3 (18.9 to 19.8)

‡ Source: 2000 Census Summary File 4

† Source: the present analysis. ‘City’ area may therefore differ slightly from official figures.

Green space data

We used the National Land Cover Database for 2001 (NLCD 2001) to quantify green space coverage (hereafter referred to as “greenness”) within each city. The NLCD identifies 29 land cover types derived from satellite imagery at 30 m cell resolution. [21] Our definition of green space included parks, lawns, golf courses, woodlands, wetlands, and other vegetated areas. These classes however do not comprehensively identify all urban green space; the NLCD also identifies four classes of land use in which built-on land is mixed with natural vegetation. The proportion of impervious (i.e., built-on) land is provided for each of these four classes, and we assumed each class had its range mid-point of impervious cover when calculating its green space area. Class 22, for example, is designated ‘Developed, low intensity’ with 20-49% impervious cover, hence we assumed the class represented 35% impervious cover and 65% green space. Class 24 (Developed, high intensity) with more than 80% impervious cover was excluded from the green space calculation as aerial photography suggested that vegetation cover in this class was rare. All assumptions about land cover were checked via aerial photography and appeared reasonable. Large, unpopulated areas of (non-green) peripheral land and/or water which were within the city boundary were excluded from our green space coverage calculations; green space was thus measured to the edge of the true ‘urban area’.

Quantifying city-level green space coverage

The simple proportion of green space land cover within each city would not have adequately captured the relationship between a city population and the city’s green space. This is because greener neighbourhoods in US cities tend to be suburban and sparsely populated. We therefore calculated a population-weighted greenness value for each city, relating the spatial distribution of the population within a city to the distribution of its green space. To do this, the green space coverage for all US Census tracts (plus a 1 km buffer) within each city was calculated (census tracts are spatial units with an average population of about 3900 people and an average area of $10km^2$). The green space coverage for the city was then summed and averaged, weighting the coverage in and around each census tract by its resident population.

It is important to note that our unit of analysis remained the city; this population weighting served simply as an adjustment to better reflect the relationship between where the people lived within a city, and where the green space was. City greenness averaged 51% of land area in the 49 cities (range 19 to 69%).

Health data

We obtained age-standardised rates of mortality for the year 2004.[20] Four leading causes of death were selected for analysis: heart disease, diabetes, lung cancer, and motor vehicle fatalities, as well as total (all-cause) mortality. Heart disease and diabetes were included as causes of death with aetiological pathways that may be plausibly linked with green space through the protective effect of physical activity [22, 23] and the stress-reducing and other restorative effects of contact with nature. There is also empirical evidence for the association between green space and cardiovascular mortality.[6, 24] Following Mitchell and Popham,[6] we also selected lung cancer as a cause of death which was not expected to be related to green space, but which would show association with other potential confounders. Traffic fatalities were included because of their possible relationship to urban form.[25] The 49 cities had an average of 27,000 deaths in 2004.

Confounders

We were concerned at the potential for confounding variables to influence any observed association. In particular, the socio-economic characteristics of cities were likely to have a strong impact on their mortality rate. Other aspects of the cities' physical and built environments might also have influenced mortality rates and were likely to be associated with city greenness.[26] We obtained data describing median household income (in 1999) and percent non-Hispanic white population (in 2000) for each city from the 2000 Census Summary File 4. We obtained average concentrations of the air pollutant PM_{10} (particulate matter with a median diameter ≤ 10 μm) for each city from the US Environmental Protection Agency.[27] We obtained two alternative measures of urban form and function: the proportion of households without an automobile (a measure of automobile dependence) from US census data, and a Sprawl Index [28] incorporating concentration of housing and population; integration of homes with activities of daily life; the presence of economic and social centres; and the connectedness of street networks.

Analyses

Linear regression was used to investigate whether city-level greenness was associated with cause-specific mortality. Models were run separately for men and women since Richardson and Mitchell observed stark gender differences in the relationships between green space and mortality in their UK study.[24] City greenness was initially modelled as a continuous variable to assess whether linear relationships were present. A categorical green space variable was then produced by grouping cities into tertiles, representing low (20 to 45%), medium (46 to 58%) and high (59 to 72%) levels of greenness. If the standardised residuals of a model revealed significant departure from normality, the model was re-run with the exclusion of the largest outlier. We found that automobile dependence had more explanatory power than the Sprawl Index. The results we report thus adjust for automobile dependence rather than sprawl.

RESULTS

Table 1 illustrates the variation in greenness across the sample. Scatter plots revealed that all-cause mortality rates were generally higher in greener cities (Figure 1), although the trend was weak for both males and females. Adjustment for city-level average household income, ethnicity, air pollution, and automobile dependence rendered the relationship non-significant in the whole sample (data not shown). However, there were two clear outliers in the relationship; Las Vegas and Tucson. Their removal uncovered a significant relationship between city greenness and all-cause mortality. Each percentage point increase in city greenness was associated with an additional 6.1 male and 3.5 female deaths per 100,000 population (Table 2). Table 2 shows that we found no other significant independent relationships between city greenness and cause-specific mortality.

When investigating effects at different levels of city greenness, we found the largest effect sizes for all-cause mortality in the greenest cities (Table 3), which was indicative of a dose-response relationship. Compared with the least green cities the greenest cities had 133 more male deaths and 94 more female deaths per 100,000 population in 2004, after adjustment for income, ethnicity, and air pollution (and removal of the same two outlying cities).

Figure 1: Relationship between all-cause mortality (age-standardised rate) and city greenness for (a) males and (b) females. Unadjusted linear best-fit predictions have been superimposed. The two outlying cities have been labelled.

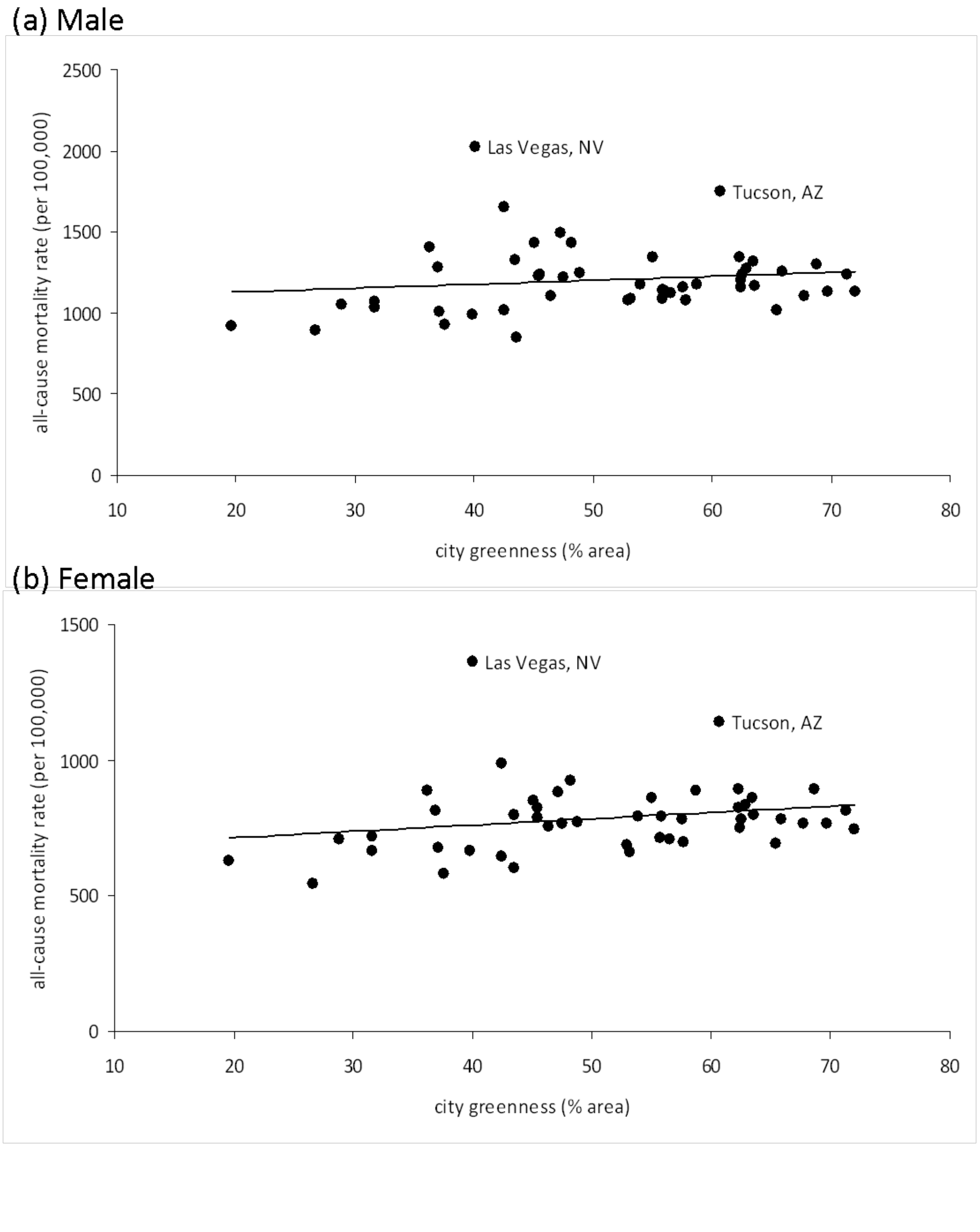

Table 2. Linear regression results for the relationship between city greenness and cause-specific mortality rates.

Cause of death	Male	Female
All causes	6.13 (1.93 to 10.32)** §	3.47 (0.71 to 6.22)* §
Heart disease	-0.51 (-3.19 to 2.16)	-0.49 (-2.17 to 1.19)
Diabetes	0.26 (-0.02 to 0.55)	0.18 (-0.01 to 0.37)
Lung cancer	0.22 (-0.44 to 0.87)	0.06 (-0.39 to 0.50)
Motor accident	0.07 (-0.27 to 0.41)	-0.14 (-0.34 to 0.05)

* $0.01 \leq p < 0.05$

** $0.001 \leq p < 0.01$

§ denotes that Las Vegas and Tucson were excluded

Models adjusted for socioeconomic deprivation (median household income), ethnicity (percentage non-Hispanic white), particulate air pollution (PM10), and car dependency (% households with no car). Regression coefficients (plus 95% confidence intervals) indicate the change in rate per 100,000 population associated with a percentage point increase in city green space coverage. If removal of outliers was necessary to normalise model residuals this is indicated and the result is included only if this changed the substantive finding (i.e., from non-significance to significance, or vice versa).

Table 3. Linear regression results for the relationship between city greenness groups (low, medium and high) and cause-specific mortality rates.

Cause of death	City greenness	Male	Female
All causes	Low	§ 1.00	§ 1.00
	Medium	§ 84.91 (-12.60 to 182.43)	§ 51.39 (-10.28 to 113.06)
	High	§ 132.90 (18.33 to 247.46)*	§ 94.21 (21.76 to 166.66)*
Heart disease	Low	1.00	1.00
	Medium	-19.67 (-78.12 to 38.77)	-7.64 (-44.82 to 29.54)
	High	6.49 (-62.46 to 75.45)	1.90 (-41.96 to 45.76)
Diabetes	Low	1.00	1.00
	Medium	5.40 (-0.87 to 11.67)	3.31 (-0.92 to 7.54)
	High	4.34 (-3.06 to 11.73)	4.18 (-0.81 to 9.17)
Lung cancer	Low	1.00	1.00
	Medium	-2.77 (-16.91 to 11.36)	-5.03 (-14.57 to 4.50)
	High	7.93 (-8.75 to 24.60)	2.47 (-8.78 to 13.72)
Motor	Low	1.00	1.00

accident	Medium	-3.97 (-11.32 to 3.38)	-2.38 (-6.70 to 1.95)
	High	0.55 (-8.13 to 9.22)	-3.37 (-8.47 to 1.74)

* $0.01 \leq p < 0.05$

§ denotes that Las Vegas and Tucson were excluded.

Models were adjusted for socioeconomic deprivation (median household income), ethnicity (percentage non-Hispanic white), particulate air pollution (PM10), and car dependency (% households with no car). Regression coefficients (plus 95% confidence intervals) indicate the difference in rate per 100,000 population associated with that group, compared with the least green cities. If removal of outliers was necessary to normalise model residuals this is indicated and the result is included only if this changed the substantive finding.

DISCUSSION

We examined the association between city greenness and mortality in large US cities. After controlling for differences in income, ethnic composition, air quality, and automobile dependence, city greenness was not associated with mortality from heart disease, diabetes, lung cancer, or motor vehicle crashes. It was however, weakly associated with increased all-cause mortality. The lack of association with mortality from heart disease and diabetes was unexpected and in contrast to results from some (but not all [29]) existing individual- and neighbourhood-level studies. The positive association between green space and all-cause mortality was also unexpected.

Our study is the first, as far as we are aware, to specifically investigate the association between green space coverage and health at the *city* level. The research benefited from national coverage and a large sample population (43 million). Both our land cover and health data were of high quality. Population weighting the city-level greenness measure took account of any extreme spatial dissonance between the population of the city and its green space.

Ecological studies are often criticised for their vulnerability to the ecological fallacy; the mistaken assumption that associations observed at a group or population level always apply at the individual level. In this study however, we were not seeking to infer anything about the individual-level relationship between green space and health. We were instead seeking to estimate an association between city-level environment and population health, mindful of the current attention on green space as a potentially useful salutogenic property of urban environments.[30] Urban planning and design has the capacity to alter the health-related environment for large numbers of people. It is therefore important to assess associations between environmental exposures and health outcomes at a genuinely population level. Cities provide the ideal units of analysis for this work as they will encompass individuals' daily movements more adequately than smaller neighbourhood geographies.

We should interpret the study results in the light of several important limitations however. First, our measure of city greenness was crude; it lacked specification of the type of space and the nature of the contact between it and the user population. In our study, the ‘greenness’ provided by monotonous lawn-edged streets was not distinguished from that provided by forested urban parks, for example. Furthermore, contact with green space is not a straightforward, one-dimensional exposure. The ‘green’ in arid Phoenix will be different from that in verdant Atlanta. Winter ‘green’ differs from summer green, and streets lined by dogwood have a different look and feel than streets lined by oak and poplar. Green exposure may be experienced differently in high-density cities than in low-density cities, by those who walk through it than by those who simply view it from windows, by those who live in high-rise buildings than by those who live at ground level, and by those who feel safe in it than by those who feel threatened. We did not capture any such subtlety with our single continuous variable; we captured ‘greenery’. However, from this limitation of our study springs a useful message for planners; if we green our cities without attention to the form the green spaces take, and the kinds of contact that residents want to have with their natural environment, there may be no benefit for population health. Future research could focus on trying to distinguish between different configurations of green spaces within the cities, or quantifying differing types of ‘green’ land cover.

A second limitation was our inability to address the possibility of selection bias. If healthier people tend to gravitate toward less green cities, (and some of the least green such as New York or San Francisco, offer economic and social opportunities attractive to healthy migrants), whilst sicker (or more at-risk) people tend to gravitate toward greener cities, (perhaps seeking a softer, less ‘urban’ environment), then any health benefit of green cities would be obscured. Our use of a cross-sectional study design also precluded causal inference. Third, the mortality data was from 2004 while the independent variable data dated from three to five years earlier. Given the latency of many green space-related health conditions we do not expect this will have adversely affected the findings. Finally, while we controlled for several key influences on the chronic diseases in question, residual confounding is likely. We were not able to adjust for smoking rates or dietary behaviour, for example. These factors, singly or in combination, could account for our unexpected result: not only a failure of green space to show any health benefit, but a tendency for greener cities to have higher mortality rates.

Our failure to identify an association between city greenness and city-level mortality rates does not mean that contact with green space is not salutogenic; there is strong experimental and observational evidence for a salutogenic effect. What else could account for the disparity between our results and those of most prior studies? We suggest that the answer lies, at least in part, in the spatial scale of our analysis. Greener cities are more likely to be less compact and more sprawling, with higher travel demand and greater automobile dependency. Indeed, greener cities were more automobile dependent in our data set ($p < 0.001$ after adjustment for socioeconomic deprivation and ethnicity). Whilst our models account for automobile dependency in the sense of what proportion of the population has no car, they could not account for the behaviours that an automobile-dominated life brings. Increased reliance on automobile travel replaces active transportation.[26] Greener cities might also incorporate less healthy features at the macro scale, such as physically dispersed communities and more residential social stratification. These macro-scale features, in turn, may undermine the health benefits of contact with green spaces. It is also possible that our results are peculiar to the USA, with its distinct urban morphology and car-oriented lifestyle. Similar studies in other urban and cultural contexts would be valuable. The unexpected positive relationship between green space and all-cause mortality (significant after exclusion of outliers) may plausibly be related to the link between greener cities and car dependency in the US.

In neighbourhood-level research, the assumption is often made that people with relatively more green space in their area have more physical or visual contact with it than people with relatively less green space in their area. Perhaps analysis at the city scale stretches that assumption to breaking point. Even with a population-weighted measure of city greenness perhaps the relationships between exposure and outcome are too loose. Further research on this would be useful, because it might help reveal more appropriate planning scales when thinking about designing greener cities.

Our findings have important implications for policymakers. If green space is a health amenity in cities, as evidence suggests, its scale and context are likely to be important. The provision of green space at the neighbourhood scale should be balanced by attention to density, connectivity, mixed land use, transportation infrastructure, and other metropolitan-scale predictors of good health. Improving green space provision without consideration of the implications for other societal functions, such as transportation, may not produce the predicted population health benefits.

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ETHICS
No ethical approval was required for the analyses of these secondary, aggregate data.

CONTRIBUTIONS
All authors designed the study. TAB and ER carried out the data preparation, and initial analyses. ER undertook the final analyses and wrote the first draft. All authors have commented on, edited and approved the final draft. RM is the guarantor.

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